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**Title : Comparative Study on Long Term Climate Data Sources over
South Korea**

Short Title : Long Term Climate Dataset Comparison over South Korea

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Abstract

Long term climate data are vitally important in reliably assessing water resources and water related hazards, but in-situ observations are generally sparse in space and limited in time. Although there are several global datasets available as substitutes, there is a lack of comparative studies about their suitability at different parts of the world. In this study, to find out the reliable century-long climate dataset in South Korea, we first evaluate multi-decadal reanalyses (ERA-20cm, ERA-20c, ERA-40 and 20th century reanalysis (20CR)) and gridded observations (CRUv3.23 and GPCCv7) for monthly mean precipitation and temperature. In the temporal and statistical comparisons, CRUv3.23 and GPCCv7 for precipitation and ERA-40 for temperature perform the best, and ERA-20c and 20CR also indicate meaningful agreements. For ERA-20cm, it has only a statistical agreement, but the mean has the difficulty in representing its ensemble. This paper also shows that the applicability of each dataset may vary by region and all products should be locally adjusted before applied in climate impact assessments. These findings not only help to fill in the knowledge gaps about these datasets in South Korea but also provide an useful guideline to the readers on the comparative performance of the global datasets in this part of the world.

Keywords : climate data sources, interannual variability, non-parametric trend test, skill score, reanalysis

49 **Introduction**

50

51 To adapt and mitigate climate change, it is essential to analyse the reliable long-term climate
52 dataset. Although the gauged local data are generally considered as the best values, they are usually
53 sparse and limited in the time range (Simmons et al. 2004; Becker et al. 2013). For this reason, the
54 availability of the highly accessible and reliable gridded dataset has been developed since 1980s, and
55 some research groups, such as the Climate Research Unit (CRU) and the Global Precipitation
56 Climatology Centre (GPCC), have constructed the monthly precipitation or temperature dataset by
57 applying their own interpolation methods based on observations worldwide (Chen et al. 2002;
58 Becker et al. 2013; Harris et al. 2014). They have had an important role in trend analysis in areas
59 lacking local observations and global climate change analysis (Nicholson et al. 2003; Fekete et al.
60 2004; Dinku et al. 2008; Zhang & Zhou 2011; Nikulin et al. 2012). The other surrogates for local
61 observations are reanalysis products derived using modern data assimilation techniques, which have
62 been increasingly applied in climate impact studies. Representatively, the European Centre for
63 Medium-Range Weather Forecasts (ECMWF) and the National Oceanic and Atmospheric
64 Administration (NOAA) have produced these kinds of products. Initially, most reanalysis datasets
65 were only able to cover from the mid-twentieth century to present (Compo et al. 2011), e.g. the first
66 National Centers for Environmental Prediction/National Center for Atmospheric Research reanalysis
67 (NCEP/NCAR) : 1948-present (Kalnay et al. 1996); ECMWF 45-year reanalysis (ERA-40) : 1975-
68 2002 (Uppala et al. 2005); Japan Meteorological Agencies Reanalysis (JRA-25) : 1979-present
69 (Onogi et al. 2007); ECMWF reanalysis interim (ERA-interim) : 1989-present (Dee & Uppala 2009;
70 Dee et al. 2011b). However, a few of recent reanalyses such as NOAA 20th century reanalysis v2c
71 (20CR), ECMWF 20th century atmospheric model ensemble (ERA-20cm), and ECMWF 20th century
72 assimilating surface observations only (ERA-20c) extended the data period up to the whole 20th
73 century (Compo et al. 2011; Hersbach et al. 2015; Poli et al. 2016). Moreover, those reanalyses are

74 able to perform on daily or sub-daily scales as well as monthly scales, while the interpolated datasets
75 only provide monthly values. Nevertheless, because these datasets are not directly taken from
76 observations, they have additional uncertainties (Dee et al. 2011a; Hersbach et al. 2015). Hence, it is
77 essential to evaluate their qualities in order to use these products in the climate change study.

78 To examine the quality of these data sources, there have been a lot of global-, continental-, or
79 local-scale studies. For instance, Simmons et al. (2004) compared ERA-40 and NCEP/NCAR
80 reanalysis to CRU data for air temperature (CRUTEM2v) at $5^{\circ}\times 5^{\circ}$ resolution on global and
81 continental scales and concluded that there was very similar variability between CRUTEM2v and
82 ERA-40, especially in Northern Hemisphere from 1979 onward. In the global comparison between
83 interpolated observations and reanalysis data with $3.75^{\circ}\times 2.5^{\circ}$, Donat et al. (2014) showed that ERA-
84 40 and ERA-interim had a better agreement than NCEP/NCAR and JRA-25 for the extreme
85 temperature, and the reanalysis products for extreme precipitation performed with a low agreement
86 but still correlated significantly. In the case of a national-scale evaluation, the performance over Iran
87 was done by Raziei et al. (2011) by comparing GPCC Full Data Reanalysis Product Version 3
88 (GPCCv3) and NCEP/NCAR precipitation dataset, which showed that GPCCv3 could complement
89 the observations but NCEP/NCAR had significant discrepancies before 1970s. A recent study over
90 China by Gao et al. (2016) statistically evaluated ERA-20cm, the latest ECMWF twentieth-century
91 reanalysis dataset. After comparing the each ensemble at $0.5^{\circ}\times 0.5^{\circ}$ grids for precipitation and
92 temperature, it was concluded that generally all ensemble simulations were able to represent the real
93 condition on a comparable level.

94 It is important that comparative studies should cover a wide range of locations around the world
95 and gaps should be filled in for the sites lacking such studies so that a clear pattern could be
96 understood. In South Korea, the long-term climate trend analysis on precipitation and temperature
97 has generally been based on the observed values (Chung & Yoon 2000; Chung et al. 2004; Chang &
98 Kwon 2007; Bae et al. 2008; Jung et al. 2011) and the time range of these studies were limited in the

late 20th century. There were a few trials to apply the interpolated datasets or reanalysis products on the climate trend research over Korea, but these datasets were applied to estimate the features of the comparable region like East-Asia, not South Korea itself (Ho et al. 2003; Jeong et al. 2015; Choi et al. 2016). In other words, the climate datasets were used in Asian area to compare with the climate trend of Korea examined by the daily observation data. In South Korea, the number of stations over 50 years is less than 15, although there are hundreds of gauging stations that have been installed. For this reason, the time period for climate impact assessment has been limited up to the mid-twentieth century in South Korea. Thus, if the researchers would like to extend the study period, it is essential to attempt to find out the reliable long-term dataset with high resolution, which should be explored. However, as aforementioned, there has not been a lack of evaluation for the reliability and applicability of century-long reanalyses as well as observation-based global climate data over South Korea.

Given this background, this study has selected several century-long precipitation datasets (ERA-20cm, ERA-20c, 20CR, CRU TS v.3.23 (CRUv3.23) and GPCC Full Data Reanalysis Product Version 7 (GPCCv7)) and temperature datasets (ERA-20cm, ERA-20c, 20CR and CRUv3.23), covering the whole 20th century. ERA-40 has also been considered as a benchmark for a half century reanalysis. By estimating the temporal variability, trend and statistical agreement for monthly values of each dataset in South Korea, this study focuses on the applicability, uncertainty and limitation of those multi-decadal datasets in the country-scale climate change study. For evaluation, we have assessed correlation coefficient r , the significance of trend by the Mann-Kendall test, and the skill score based on the probability density functions (PDFs). The specification of the datasets and methodology applied in this study are introduced at first and the main results for precipitation and temperature are followed. Finally, the discussion and conclusions are presented.

124 **Data**

125
126 **Observed Local Data**

127 To analyse the precipitation and temperature change over the mainland of South Korea, daily total
128 precipitations and daily mean 2-m air temperatures of 13 ground gauge stations, spanning 1961-2010,
129 are taken from the data archive of Korea Meteorological Administration(KMA)
130 (<https://data.kma.go.kr/cmmn/main.do>) and merged to the monthly values. In order to compare the
131 datasets for the common period, the stations are evenly selected excluding islands of Korea from
132 1961 to 2001 with no empty values, although three of them are available from 1966, 1968 and 1973,
133 separately. The quality of the observations is strictly controlled by KMA. The detailed information
134 on the location and data period of the stations is given in Figure 1 and Table 1.

135

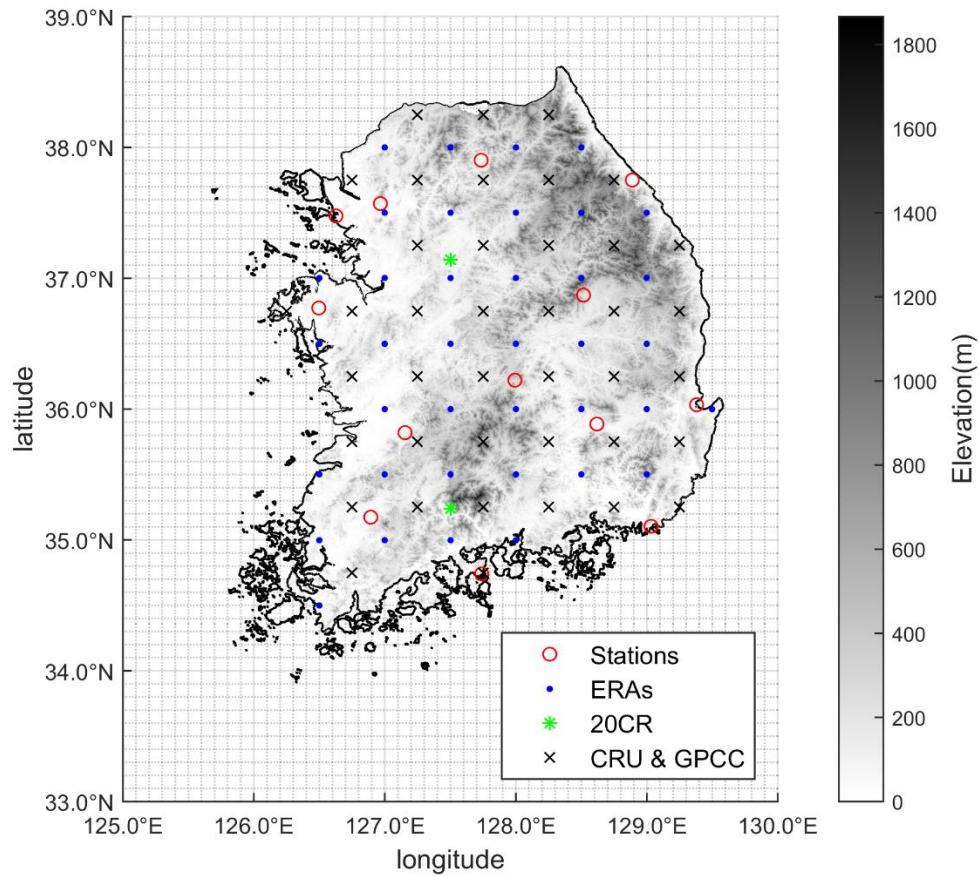
136 Table 1 Longitude, latitude and observation period of the selected stations

No.	Name	Longitude	Latitude	Observation Period	Elevation(m)
1	Seoul	126-57-56 E	37-34-17 N	1961-2010	11.1
2	Incheon	126-37-29 E	37-28-39 N	1961-2010	69.6
3	Seosan	126-29-45 E	36-46-25 N	1967-2010	30.3
4	Chuncheon	127-44-08 E	37-54-09 N	1966-2010	79.1
5	Gangneung	128-53-27 E	37-45-05 N	1961-2010	27.4
6	Jeonju	127-09-17 E	35-49-17 N	1961-2010	54.8
7	Chupungnyeong	127-59-40 E	36-13-11 N	1961-2010	246.1
8	Yeongju	128-31-00 E	36-52-18 N	1973-2010	212.2
9	Gwangju	126-53-29 E	35-10-22 N	1961-2010	73.8
10	Yeosu	127-44-26 E	34-44-21 N	1961-2010	66.0
11	Daegu	128-37-08 E	35-53-06 N	1961-2010	65.5
12	Pohang	129-22-46 E	36-01-57 N	1961-2010	3.7
13	Busan	129-01-55 E	35-06-16 N	1961-2010	71.0

137

138 Figure 1 Locations of 13 gauge stations shown in Table 1 and gridded points of ERAs (ERA-20cm, ERA-
139 20c and ERA-40), 20CR, CRUv3.23 (CRU) and GPCCv7 (GPCC)

140



Reanalysis Data

ERA-20c is the first atmospheric 20th century reanalysis of the ECMWF. This dataset, covering 1900-2010, is produced by assimilating observations of surface pressure and surface marine winds only (Poli et al. 2016). Considering the data availability and resolution of other datasets, we extract total precipitation from the 24 hour accumulated forecasts and 2-m air temperature from 6 hourly analysis data with $0.5^\circ \times 0.5^\circ$ grid from January 1901 to December 2010 via the ECMWF web server. The products in South Korea are accumulated into monthly data and the values over the sea are excluded.

In addition to ERA-20c, the ECMWF also released ERA-20cm data with 10-member ensemble from January 1900 to December 2010 (Hersbach et al. 2015). Comparing with ERA-20c, this dataset was produced with the same Integrated Forecasting System(IFS) version Cy38r1, but it includes no

154 data assimilation (Donat et al. 2016). 3-hourly total precipitation and temperature data with $0.5^{\circ} \times 0.5^{\circ}$
155 grid from January 1901 to December 2010 are extracted from the web server and they are calculated
156 as inland monthly datasets. In this study, to explore the general feature of ERA-20cm ensemble, we
157 use the ensemble mean and the ensemble member 0 (hereafter “En0”) only. A more detailed
158 assessment on all ten ensemble members will be covered in another study.

159 To find out the difference among the ECMWF products, another data called ERA-40, the 45-year
160 reanalysis data from September 1957 to August 2002 (Uppala et al. 2005), are extracted from the
161 ECMWF archive in the same way as ERA-20c. We collect the 6-hourly convective precipitation data,
162 large-scale precipitation data and 2-m air temperature data at $0.5^{\circ} \times 0.5^{\circ}$ grid from January 1961 to
163 December 2001. The total precipitation is produced by the sum of convective and large-scale
164 precipitation excluding the values on the sea and the products are aggregated into monthly data.

165 20CR is one of the long term reanalysis datasets provided by the NOAA. Its latest version 2c,
166 spanning 1850 to 2014 with the $1.875^{\circ} \times 1.9^{\circ}$ resolution, is produced by assimilating only surface
167 pressures and using Ensemble Kalman Filter technique to produce 56 ensemble members (Donat et
168 al. 2016). Because each ensemble dataset is not available in the web server, we collect only 8-times
169 daily ensemble means for total precipitation and 2m air temperature from 1901 to 2010 and
170 accumulate them on a monthly basis. As with other datasets, the data over the sea are ignored.

171

172 **Gridded observations by CRU and GPCC**

173 CRU TS v.3.23 (CRUv3.23) is the recently updated time-series land-only dataset from 1901 to
174 2014, which covers all over the world except the Antarctic (Harris et al. 2014). This dataset
175 constructed by using the Climate Anomaly Method based on the worldwide observations provides
176 monthly total precipitation and monthly mean 2-m air temperature with its highest resolution
177 ($0.5^{\circ} \times 0.5^{\circ}$ latitude/longitude) (Harris et al. 2014). In this paper, for the comparison with the
178 observations and reanalysis dataset, the data over South Korea from 1901 to 2010 are extracted.

GPCC has produced the global land-surface precipitation data, and its recent version, GPCC Full Data Reanalysis Version. 7.0 (GPCCv7), covers a 111-year analysis period from 1901 to 2013 based on the rain gauge database over 51,000 stations worldwide (Schneider et al. 2015). In this study, the monthly total precipitation product with its highest resolution of $0.5^{\circ} \times 0.5^{\circ}$ over South Korea from 1901 to 2010 is taken from this dataset.

Methodology

Evaluation of interannual variability

To explore the temporal strength of the linear relationship between the model products and the observed values, the Pearson's linear correlation coefficients(r) mean between the products and the observations of 13 stations from 1961 to 2001 are calculated. This method has been widely used to measure the degree of collinearity between the observed and the modelled data in the multi-decadal climate variability studies, although it is oversensitive to high extreme values and insensitive to proportional gaps between two variables (Legates & McCabe 1999; Deser et al. 2004; Herrmann et al. 2005; Dickinson et al. 2006; Wu et al. 2010; Gholami et al. 2015; Wang et al. 2015). Here, we focus on the variability between the observation and the modelled datasets using r , while the absolute differences between them are simply explored through figures on seasonal/annual change.

For this analysis, the seasonal/yearly total precipitation and mean temperature variables are derived from all the datasets. Every seasonal dataset is collected for Spring from March to May, Summer from June to August, Autumn from September to November, and Winter from December to February.

In case of r , considering the difference in coordinate and resolution between datasets (Figure 1), we have interpolated the data in each station point by using an inverse distance (ID) method, one of

the most applied deterministic methods (Babak & Deutsch 2009). Compared with other preferred methods, kriging, the ID method is simple to calculate, more applicable to spatial estimation with small sized observation networks and does not require prior information like a semi-variogram model (Tomczak 1998; Lu & Wong 2008; Babak & Deutsch 2009). For this reason, this study has applied the ID method as follows :

$$w(x,y) = \sum_{i=1}^N \alpha_i w_i, \quad \alpha_i = \frac{\left(\frac{1}{d_i}\right)^p}{\sum_{i=1}^N \left(\frac{1}{d_i}\right)^p} \quad (1)$$

where N is the number of the grids used in calculation, w is the evaluated value from the data product in each station point, w_i is the i -th data point among the selected values, d_i is the distance from the station to the i -th grid, and p is the specified weighting power. In this equation, the weighting parameter, p , can vary from 0 to infinite, and when the value increases, the estimated is less influenced by the further stations (Chang et al. 2006). In this analysis, all inland gridded values are used and the most common value, 2, is applied for the power p (Teegavarapu & Chandramouli 2005; Babak & Deutsch 2009). After calculating the r in 13 stations, the mean r values of them are compared.

217

218 **Trend test**

The correlation coefficient, r , does not represent the slope of the line of the best fit, although it shows the relationship between the observed and the model. Thus, to find out the significance of linear trends in each dataset, the Mann-Kendall test is applied for the reference period 1961 – 2001. The trends from 1901 to 2010 of several precipitation datasets (ERA-20cm, ERA-20c, 20CR, CRUv3.23 and GPCCv7) and temperature datasets (ERA-20cm, ERA-20c, 20CR and CRUv3.23) are also evaluated in order to assess the long-term patterns of them throughout the 20th century. The Mann-Kendall trend test created by Mann (1945) and Kendall (1955) is one of the widely used nonparametric tests for detecting the trend of environmental data such as precipitation, temperature

227 and streamflow (Xu et al. 2005; Bae et al. 2008; Shadmani et al. 2012; Zang & Liu 2013). Compared
 228 with parametric tests like linear regression which require data normality as well as independence,
 229 this method only requires the independence of data (Hamed & Rao 1998; Xu et al. 2005). In the
 230 Mann-Kendall test, the test statistic S and the standardised test statistic Z are estimated by the related
 231 equations as follows :

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \quad (2)$$

$$\text{sgn}(x) = \begin{cases} 1 & \text{for } x > 0 \\ 0 & \text{for } x = 0 \\ -1 & \text{for } x < 0 \end{cases} \quad (3)$$

$$V(S) = \frac{n(n-1)(2n+S) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)}{18} \quad (4)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{S+1}{\sqrt{V(S)}} & \text{for } S < 0 \end{cases} \quad (5)$$

232 where, $x_1, x_2, x_3, \dots, x_n$ are the time series of length n , $V(S)$ is the variance of S , m is the number
 233 of tied groups, t_i is the number of ties for the i -th value, and Z follows a standard normal
 234 distribution (Xu et al. 2008). The significance of trends is evaluated by comparing Z with the
 235 standard normal variate at the desired significance (Hamed & Rao 1998). When $|Z| > Z_{1-\alpha/2}$,
 236 where $Z_{1-\alpha/2}$ is the standard normal deviates where the significance level is α , the null hypothesis
 237 is rejected and it means that there is a significant trend in the time series in the test. In this study,
 238 both 0.05 and 0.10, the most commonly used values, are applied for α , although significance levels
 239 can vary from 0.1 to 0.001 according to the study (Hamed & Rao 1998; Xu et al. 2005; Bae et al.
 240 2008; Jung et al. 2011; Zang & Liu 2013). The magnitude of the linear trend for this method is
 241 estimated by Theil-Sen approach, sometimes referred to as “Kendall Slope Estimator”, defined by
 242 the median value of the ranked slope estimates as follows (Theil 1950; Sen 1968; Hirsch et al. 1982;
 243 Xu et al. 2008; Zang & Liu 2013) :

$$\beta = \text{Median}\left(\frac{x_j - x_i}{j - i}\right), \quad \forall i < j \quad (6)$$

In this equation, the positive value of β represents the increasing trend over time, while the negative value means the opposite trend. The advantage of this method is that it is less sensitive to outliers or extreme values than the least-square method (Shadmani et al. 2012; Sayemuzzaman & Jha 2014).

PDF-based Evaluation method

To assess the statistical similarity between the observations and each dataset from 1961 to 2001, we have estimated the skill score based on the probability density function (PDF) suggested by Perkins et al. (2007). This method is very simple but powerful to capture the relative compatibility between observation and model distribution. In additional, compared with the traditional mean-based method, this performance shows more credible climate variations and it is flexible to collect data with different time periods from multiple stations (Perkins et al. 2007; Gao et al. 2016). By calculating the overlapped area between two distributions at each bin, this skill estimates how much the climate dataset distribution is similar to the observed. If a dataset matches the observed values perfectly in PDF, the skill score will be 1, which equals the sum of the probability. Otherwise, if the skill score is close to zero, it means that there is no common area between the model values and observations. In other words, the more overlapped the two curves, the closer to 1 this score is. The skill score is calculated as follows :

$$S_{score} = \sum_1^n \text{minimum}(P_m, P_0), \quad (7)$$

where n is the number of bins for the calculation, P_m is the frequency of values in a given bin from a comparison target, and P_0 is the frequency values in a given bin from observations. In this study, the monthly variables are applied and the square root of 1mm month⁻¹ for precipitation and 1°C for temperature are considered as the intervals of bins to effectively compare the PDFs like earlier

266 studies (Perkins et al. 2007; Gao et al. 2016).

267

268

269 **Results**

270

271 **Precipitation**

272 **Interannual variability**

273 Table 2 quantitatively explains the seasonal/annual correlation between the observation and the
274 simulated precipitation from 1961 to 2001. In the seasonal mean comparison, the r values for
275 CRUv3.23 and GPCCv7 exceed 0.9 in every season, and ERA-20c, ERA-40 and 20CR performs
276 moderate to high correlations($0.4 < r < 0.9$). Among seasonal values, spring and winter are more
277 correlated than summer and autumn. However, the simulations for ERA-20cm mean and En0 are
278 located between -0.149 and 0.313, which means that there is little temporal correlation with the
279 observation for precipitation. The similar result is described in the annual mean comparison.
280 CRUv3.23 and GPCCv7 perform very well with the r over 0.9 and ERA-20c follows with 0.621.
281 20CR and ERA-40 have the moderate correlations with 0.498 and 0.445, separately, but the r values
282 for ERA-20cm mean and En0 are close to zero.

283

284 Table 2 Correlation coefficient(r) for seasonal and annual total precipitation for each dataset averaged
285 over all regions from 1961 to 2001

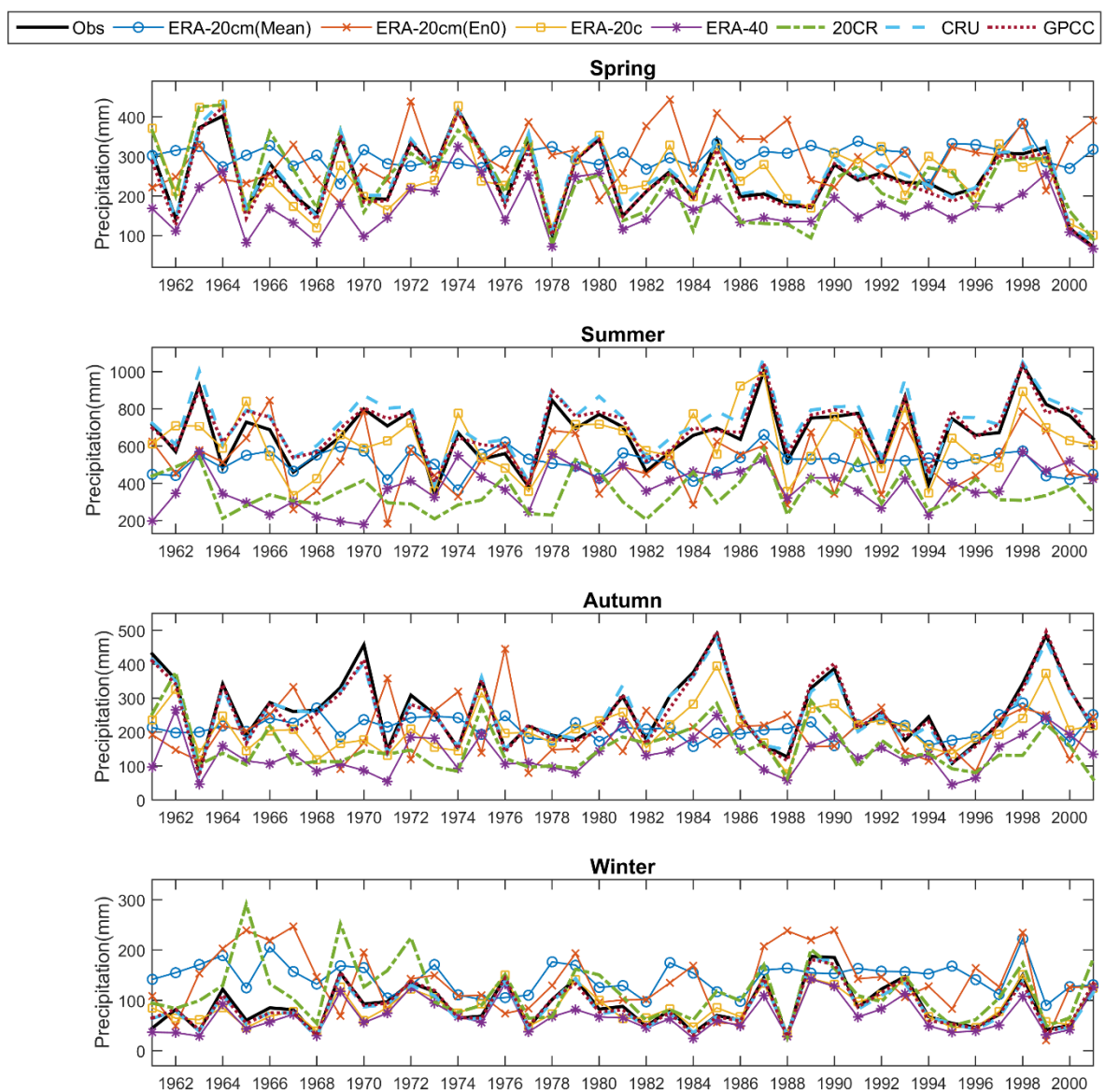
Type	Seasonal comparison				Annual comparison
	Spring	Summer	Autumn	Winter	
ERA-20cm(Mean)	-0.110	0.070	0.014	0.284	0.091
ERA-20cm(En0)	0.042	0.313	-0.149	0.225	0.246
ERA-20c	0.762	0.600	0.665	0.829	0.621
ERA-40	0.821	0.466	0.647	0.883	0.445
20CR	0.744	0.407	0.562	0.638	0.498
CRUv3.23	0.963	0.922	0.942	0.960	0.929
GPCCv7	0.970	0.938	0.952	0.966	0.945

286

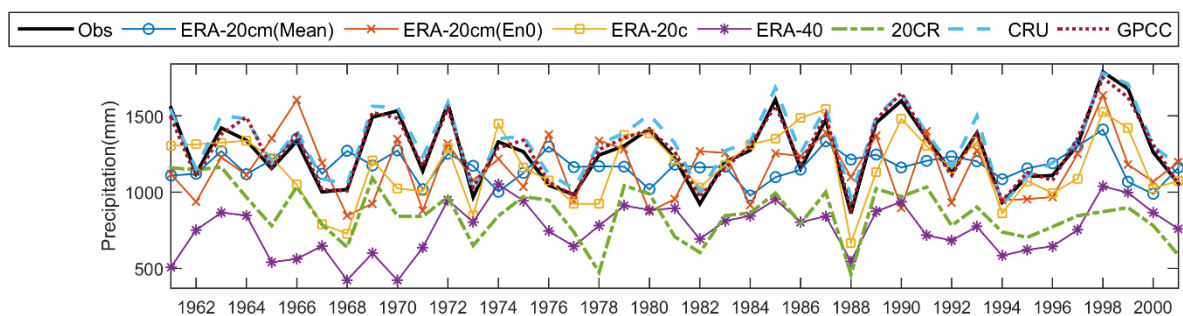
287 Figure 2 which illustrates the seasonal and annual precipitation change of each dataset from 1961
288 to 2001 supports this result. For the seasonal comparison, the fluctuations of ERA-20cm mean and
289 En0 have little correlations with the observations in all seasons, while GPCCv7 and CRUv3.23
290 perform almost in similar movements with the observed values (Figure 2(a)). For ERA-20c, ERA-40
291 and 20CR, their movements have significant similarities to the observations, but the values
292 themselves of each dataset are slightly different. For example, ERA-40 and 20CR have the lower
293 rainfall than the observation, especially, in summer and autumn, whereas ERA-20c is relatively close
294 to the observation (Figure 2(a)). This means that in terms of interannual variability, ERA-20c is less
295 biased than ERA-40 and 20CR in South Korea. The annual change shows a similar result with the
296 seasonal trend. The annual patterns of ERA-20cm mean and En0 are totally different from that of the
297 observation, while CRUv3.23 and GPCCv7 perform very well (Figure 2(b)). For ERA-20c, ERA-40
298 and 20CR, they have the partial similarity to the observation in the annual comparison, but only
299 ERA-20c has the equivalent value with the observed (Figure 2(b)). In other words, ERA-40 and
300 20CR are clearly underestimated.

301
302 Figure 2. Total precipitation change for observation (Obs), Mean of ERA-20cm (ERA-20cm (Mean)), En0 of
303 ERA-20cm (ERA-20cm(En0)), ERA-20c, ERA-40, 20CR, CRUv3.23 (CRU) and GPCCv7 (GPCC) averaged
304 over the whole region from 1961 to 2001

305 (a) The seasonal total precipitation change (from above, Spring, Summer, Autumn, and Winter)



(b) The annual total precipitation change



Long-term trend

Table 3 shows the long-term trends derived by the Mann-Kendall test. The standardised statistics

(Z) for the reference period 1961 to 2001 describe that there are no significant seasonal/annual trends at 90% or 95% confidence level for ERA-20cm, ERA-20c, CRUv3.23 and GPCCv7 as well as the observation. Only ERA-40 in summer and 20CR in spring have the increasing and the decreasing trend at 95% confidence level, separately. With 90% confidence level, a further declining trend is found in the annual trend for 20CR.

Table 3 Mann-Kendall test results for precipitation trend

Dataset	Spring		Summer		Autumn		Winter		Annual	
	Z	β	Z	β	Z	β	Z	β	Z	β
1961-2001										
Observation	-1.00	-1.38	1.13	2.78	-0.51	-0.74	0.30	0.14	-0.08	-0.39
ERA-20cm (Mean)	1.49	0.42	-0.48	-0.48	-0.30	-0.19	-0.93	-0.38	-0.12	-0.27
ERA-20cm (En0)	1.49	1.66	0.10	0.31	0.19	0.16	-0.35	-0.24	0.28	0.91
ERA-20c	-0.33	-0.43	0.19	0.45	1.20	1.06	0.62	0.26	0.39	1.43
ERA-40	-0.21	-0.16	2.01 ^a	3.44	1.43	1.02	0.39	0.16	1.47	3.95
20CR	-1.99 ^a	-2.83	0.15	0.21	-0.46	-0.27	-0.86	-0.75	-1.83 ^b	-5.11
CRUv3.23	-1.00	-1.43	1.20	2.36	-0.55	-0.78	-0.01	-0.02	-0.10	-0.42
GPCCv7	-1.02	-1.40	0.86	1.40	-0.12	-0.33	-0.06	-0.05	0.00	0.11
1901-2010										
ERA-20cm (Mean)	2.58 ^a	0.20	0.52	0.11	1.19	0.12	1.82 ^b	0.15	2.14 ^a	0.60
ERA-20cm (En0)	0.11	0.02	0.80	0.38	-0.60	-0.13	0.24	0.04	0.30	0.18
ERA-20c	4.95 ^a	1.21	3.97 ^a	2.04	4.53 ^a	1.01	5.97 ^a	0.55	6.09 ^a	5.00
20CR	-0.11	-0.02	-2.19 ^a	-0.76	-2.32 ^a	-0.48	1.84 ^b	0.25	-1.76 ^b	-1.13
CRUv3.23	0.80	0.19	3.00 ^a	1.70	1.51	0.46	-0.68	-0.07	2.72 ^a	2.13
GPCCv7	0.54	0.11	3.42 ^a	1.79	1.51	0.46	-1.35	-0.16	2.86 ^a	2.14

^a : significant trend at the 0.05 significance level. ^b : significant trend at the 0.10 significance level.

β (trends for precipitation) are in *mm/yr*.

The analysis from 1901 to 2010 shows more obvious trends. For ERA-20cm, the trends of the mean and En0 are different. ERA-20cm mean has the significant increasing trends in spring, winter and annual simulations, while En0 has no significant trends. Comparing ERA-20cm with CRUv3.23 and GPCCv7, they have no similarity in the seasonal trends and the magnitude of the slopes for ERA-20cm are generally lower than those of CRUv3.23 and GPCCv7 except winter. For instance,

327 CRUv3.23 and GPCCv7 have the increasing trends in summer with the slopes of 1.70 and 1.79, but
328 ERA-20cm mean has the upward trends in spring and winter with the slopes of 0.20 and 0.15. In case
329 of ERA-20c, it performs the obvious increasing movement in every test and has the stronger
330 increasing trend than CRUv3.23 and GPCCv7 in summer and annual tests. This shows that ERA-20c
331 can exaggerate the long-term trend for precipitation than the other datasets. On the other hand, 20CR
332 performs the downward trends in summer, autumn and annual test. That is to say, the long-term trend
333 of 20CR is in contrast with the movements of other datasets.

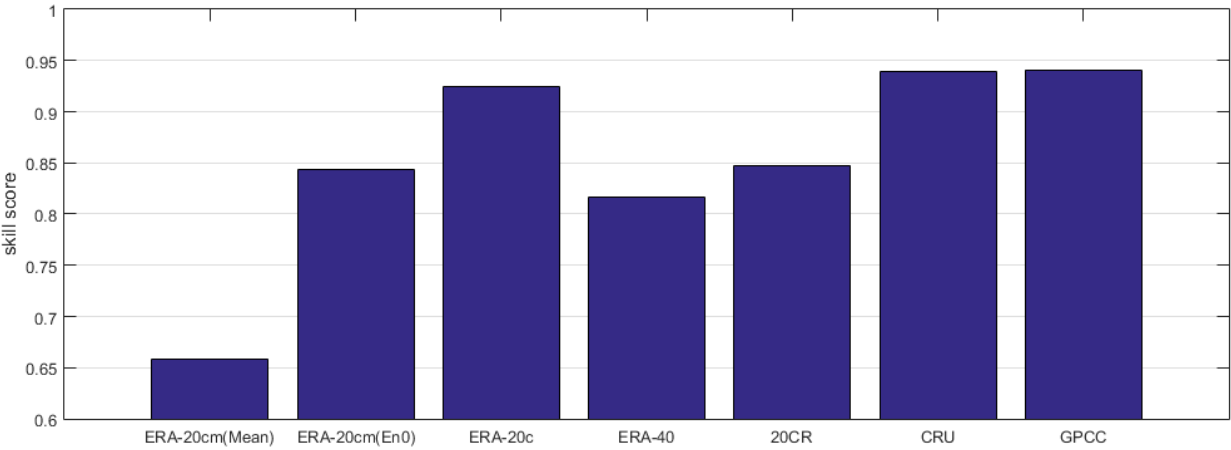
334

335 **Statistical comparability**

336 Figure 3 describes the statistical agreement between the observation and each dataset from 1961 to
337 2001. CRUv3.23 and GPCCv7 perform the best simulations with the skill score of approximately
338 0.94, and ERA-20c follows them closely with 0.93. This indicates that ERA-20c has the statistical
339 similarity with the observed at almost the same level as CRUv3.23 and GPCCv7. The scores for
340 20CR, ERA-40 and En0 are between 0.8 and 0.85 which shows significant agreements, whereas
341 ERA-20cm mean has a clearly smaller value, 0.66.

342

343 Figure 3 PDF-based skill score for monthly precipitation for the Mean of ERA-20cm (ERA-20cm (Mean)),
344 En0 of ERA-20cm (ERA-20cm(En0)), ERA-20c, ERA-40, 20CR, CRUv3.23 (CRU) and GPCCv7 (GPCC)
345 averaged over the whole region from 1961 to 2001

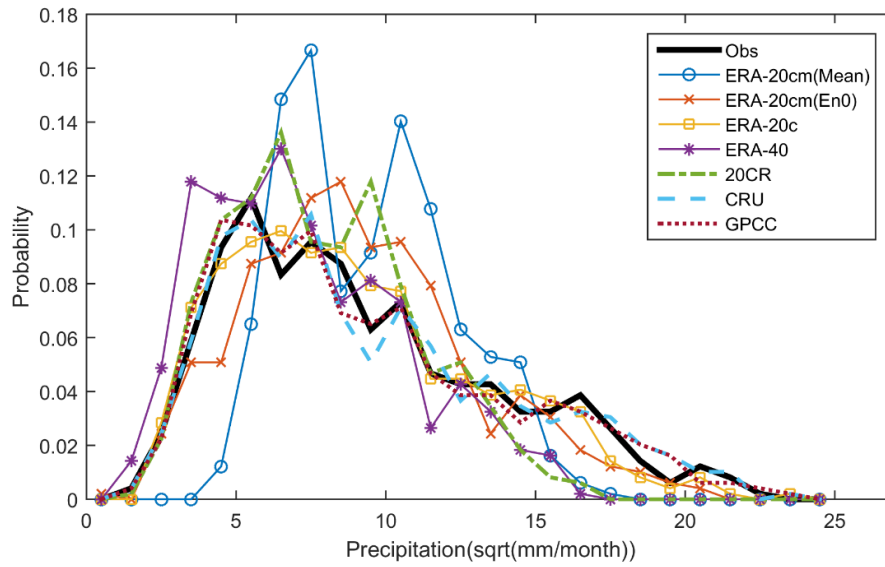


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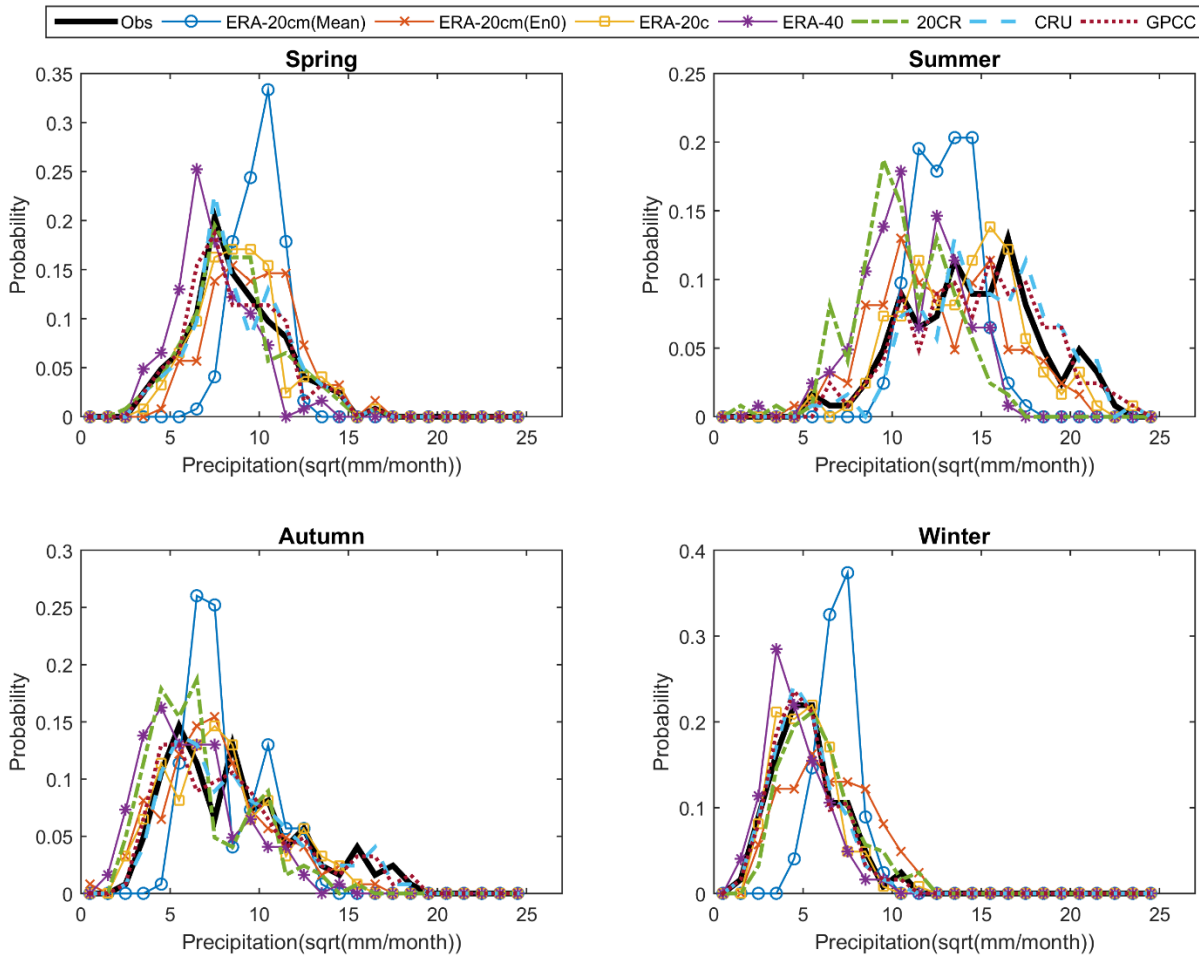
347

348 The specific discrepancies of each dataset are described in Figure 4(a) which illustrates the PDFs
 349 of the observation and each precipitation dataset over South Korea from 1961 to 2001 and Figure 4(b)
 350 which represents seasonally subdivided PDFs. It is obvious that ERA-20c as well as CRUv3.23 and
 351 GPCCv7 is one of the most fitted datasets to the observation with little discrepancies. However, the
 352 other datasets have partial gaps from the observation. For 20CR, the PDF in Figure 4(a) shows that it
 353 underestimates over 200mm month⁻¹ and overestimates in the range of 25 to 100mm month⁻¹. This
 354 result is mainly due to the underestimated values in summer, as seen in Figure 4(b). The left-biased
 355 summer rainfalls lead to overestimation of moderate values and underestimation of intensive values.
 356 The PDF of ERA-40 in Figure 4(a) overall exaggerates the frequency under 50mm month⁻¹ and
 357 underestimates over 200mm month⁻¹. It comes from the generally underestimated distributions in all
 358 seasons, especially in summer (Figure 4(b)). In case of ERA-20cm mean and En0, the dry months
 359 and intensive rainfall months are underestimated but the moderate months are overestimated in
 360 Figure 4(a). It is clear that the mean of ERA-20cm has this tendency more strongly than En0. This
 361 evaluation suggests that all datasets show the significant agreement with the observation, albeit some
 362 of them still need a cautious approach to use in the frequency analysis.

363
 364 Figure 4 Probability density functions(PDFs) for monthly total precipitation for observation (Obs), Mean of
 365 ERA-20cm (ERA-20cm (Mean)), En0 of ERA-20cm (ERA-20cm(En0)), ERA-20c, ERA-40, 20CR,
 366 CRUv3.23 (CRU) and GPCCv7 (GPCC) over South Korea
 367 (a) PDFs for monthly total precipitation from 1961 to 2001



(b) PDFs for seasonally subdivided monthly total precipitation from 1961 to 2001



Temperature

Interannual variability

Table 4 describes the r values between the gauged temperature and the model temperature from 1961 to 2001. In seasonal comparison, CRUv3.23 and ERA-40 have the highest values over 0.9 in every season and ERA-20c follows closely with 0.830 to 0.914. 20CR has the high correlations ($0.6 < r < 0.9$) and the values for ERA-20 mean and En0 are the lowest ones. To be more specific, ERA-20cm mean has the moderate correlations ($0.4 < r < 0.7$) in four seasons, while En0 has low correlations except spring. Of the four seasons, winter has the highest value except ERA-20cm mean and En0. These seasonal findings are similar to the annual simulations. In annual comparison, CRUv3.23 and ERA-40 show the most fitted correlations with the r values over 0.9 and ERA-20c closely follow them with 0.879. 20CR has the 0.808 and ERA-20cm mean (0.714) and En0 (0.523) have moderate to high correlations.

Table 4 Correlation coefficient(r) for seasonal and annual mean temperature for each dataset averaged over the whole region from 1961 to 2001

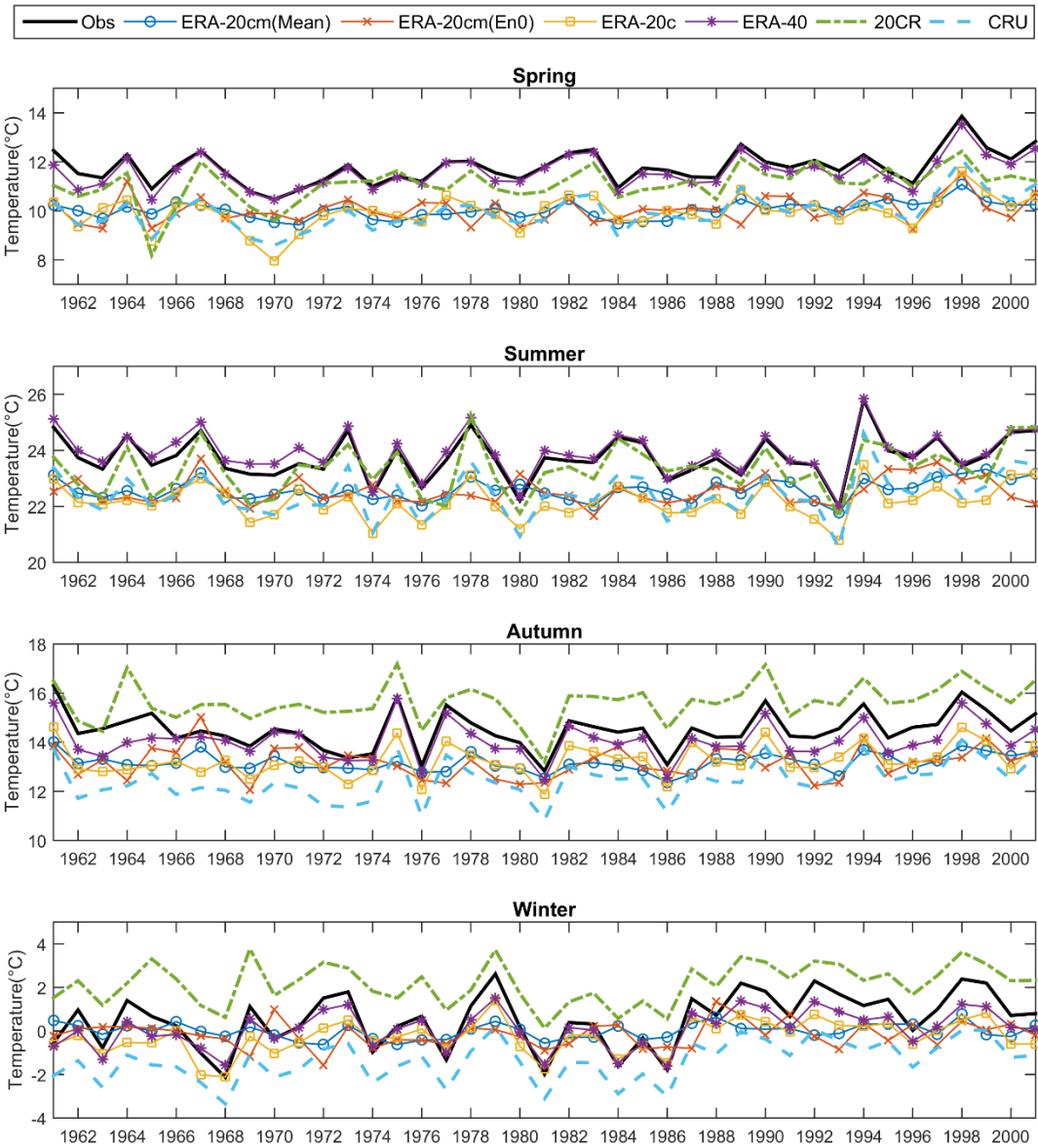
Type	Seasonal comparison				Annual comparison
	spring	summer	autumn	winter	
ERA-20cm(Mean)	0.671	0.597	0.578	0.407	0.714
ERA-20cm(En0)	0.493	0.194	0.251	0.161	0.523
ERA-20c	0.830	0.867	0.895	0.914	0.879
ERA-40	0.924	0.943	0.908	0.963	0.923
20CR	0.654	0.785	0.798	0.875	0.808
CRUv3.23	0.933	0.964	0.945	0.976	0.950

Figure 5 demonstrates the seasonal and annual mean temperature trends of each dataset over South Korea from 1961 to 2001. In Figure 5, we can see that each dataset performs the similar movements to the observations, but the values themselves are different depending on the dataset except ERA-40. For ERA-20cm and ERA-20c, the seasonal/annual variations seem to have partial correlations, but the model values are generally about 1 to 2 Celsius degrees lower than those of observations except winter season. In case of CRUv3.23, it is clear that the mean temperature for CRUv3.23 is about 2

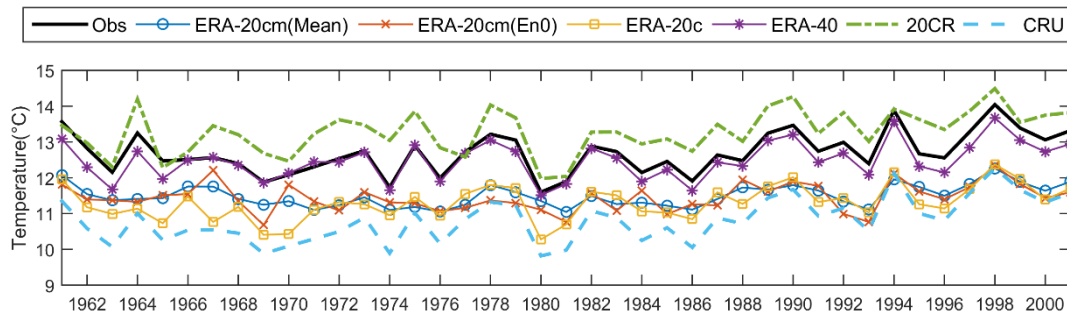
394 Celsius degrees lower than the observation in every comparison, although its variation trends have
 395 the similarity to the observations. On the other hand, 20CR has the higher values than the
 396 observation in annual comparison, affected by the autumn and winter temperature. Only ERA-40 is
 397 very well fitted to the observed values in every comparison. This result implies that, despite the
 398 significant correlations between the observation and each dataset, the bias correction should be
 399 considered before using them.

400
 401 Figure 5 Mean temperature change for observation (Obs), Mean of ERA-20cm (ERA-20cm (Mean)), En0 of
 402 ERA-20cm (ERA-20cm(En0)), ERA-20c, ERA-40, 20CR, and CRUv3.23 (CRU) averaged over the whole
 403 region from 1961 to 2001

404 (a) The seasonal mean temperature change (from above, Spring, Summer, Autumn, and Winter)



(b) The annual mean temperature change



Long-term trend

Table 5 describes the seasonal and the annual patterns of the mean temperature by the Mann-Kendall approach. In the first analysis from 1961 to 2001, the result suggests that only ERA-40 has the increasing trends in spring, winter and annual simulations as well as the observations. Seasonally, the other datasets also have the upward trend in spring, but they show the different trends in other seasons. For CRUv3.23 and ERA-20c, there are significant increasing trends in spring, autumn and winter, whereas 20CR has the trends in spring and autumn. In case of ERA-20cm, the mean has the increasing trends in spring and summer at 95% confidence level, but En0 has it only in spring at 90% confidence level. In terms of annual analysis, all datasets except En0 show the upward trends. ERA-20c, 20CR and CRUv3.23 show the significant upward trends at 95% confidence level, and ERA-40 and ERA-20cm mean suggest them at 90% confidence level. For the slope of the annual comparison, those of CRUv3.23 and 20CR are higher than the observation's, while ERA-20c and ERA-40 are slightly smaller than the observed. In case of ERA-20cm mean, the slope shows less than the half of the observation's.

Table 5 Mann-Kendall test results for temperature trend

Dataset	Spring		Summer		Autumn		Winter		Annual	
	Z	β	Z	β	Z	β	Z	β	Z	β
1961-2001										
Observation	2.62 ^a	2.53	0.57	0.64	0.84	0.70	2.30 ^a	3.65	3.66 ^a	2.09
ERA-20cm (Mean)	2.62 ^a	1.17	2.12 ^a	1.31	0.78	0.59	0.75	0.33	1.81 ^b	0.86

ERA-20cm (En0)	1.85 ^b	1.21	0.69	0.48	- 0.01	- 0.03	0.55	0.44	0.86	0.42
ERA-20c	1.67 ^b	1.40	0.46	0.33	1.92 ^b	1.30	2.62 ^a	2.38	2.71 ^a	1.80
ERA-40	2.55 ^a	2.22	- 0.08	- 0.12	0.46	0.52	2.26 ^a	2.41	1.81 ^b	1.47
20CR	2.82 ^a	2.20	1.54	1.86	2.41 ^a	2.18	1.38	1.99	2.77 ^a	2.34
CRUv3.23	3.36 ^a	3.07	1.61	1.38	2.62 ^a	2.16	2.86 ^a	3.53	3.31 ^a	2.91
1901-2010										
ERA-20cm (Mean)	8.69 ^a	1.02	7.60 ^a	0.91	6.61 ^a	0.81	6.61 ^a	0.79	9.38 ^a	0.95
ERA-20cm (En0)	4.90 ^a	1.02	4.02 ^a	0.60	4.17 ^a	0.80	3.19 ^a	0.61	6.33 ^a	0.80
ERA-20c	3.25 ^a	0.66	2.94 ^a	0.49	4.06 ^a	0.86	6.15 ^a	1.55	7.02 ^a	1.04
20CR	6.73 ^a	1.71	5.14 ^a	1.35	6.11 ^a	1.43	6.36 ^a	2.09	8.15 ^a	1.80
CRUv3.23	7.93 ^a	1.99	3.77 ^a	0.85	5.96 ^a	1.51	5.15 ^a	1.62	7.85 ^a	1.61

^a : significant trend at the 0.05 significance level. ^b : significant trend at the 0.10 significance level.

β (trends for temperature) are in $10^{-2}^{\circ} C/yr$

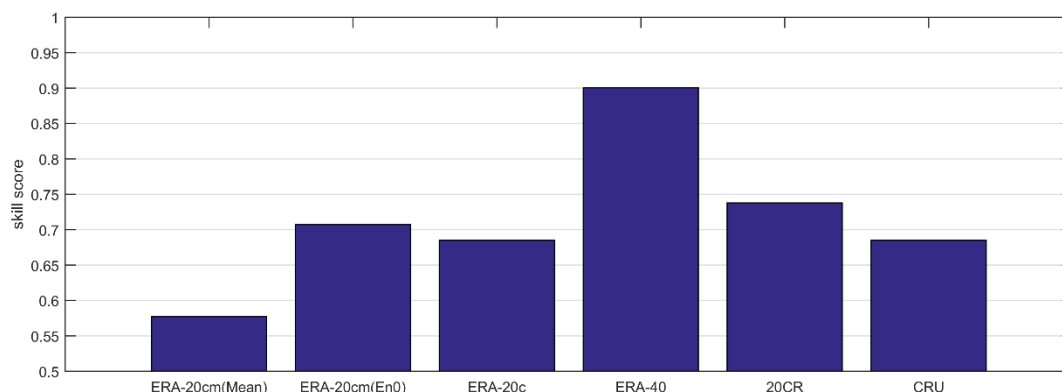
The second analysis for 20th century indicates the obvious increasing trends in all seasonal and annual simulations at 95% confidence level in Table 5. The only difference between datasets is the intensity of the slopes. As with the first analysis, the increasing magnitudes (β) of 20CR and CRUv3.23 are generally higher than those of the others. This result implies that the mean temperature in South Korea has been increased obviously over the past 100 years.

Statistical comparability

Figure 6 represents the skill score of the PDF of each dataset for monthly mean temperature from 1961 to 2001. The estimate of ERA-40 is approximately 0.90, and 20CR, En0, ERA-20c and CRUv3.23 follow with 0.74, 0.71, 0.69 and 0.69, separately. In other words, ERA-40 reanalysis has a probability density distribution approximately equal to the observed, and 20CR, En0, ERA-20c and CRU also have significant agreements with them. Reminding the high r values for ERA-20c and CRUv3.23 in annul comparison ($r > 0.87$), this result suggests that, despite the high correlation with the observation, ERA-20c and CRUv3.23 are clearly biased and they as well as other datasets need the bias correction for the application in the climate change study over South Korea. The mean of ERA-20cm also has the meaningful agreement, but not well as much as En0.

444

445 Figure 6 PDF-based skill score for monthly mean temperature for the Mean of ERA-20cm (ERA-20cm
 446 (Mean)), En0 of ERA-20cm (ERA-20cm(En0)), ERA-20c, ERA-40, 20CR, and CRUv3.23 (CRU) averaged
 447 over the whole region from 1961 to 2001



448

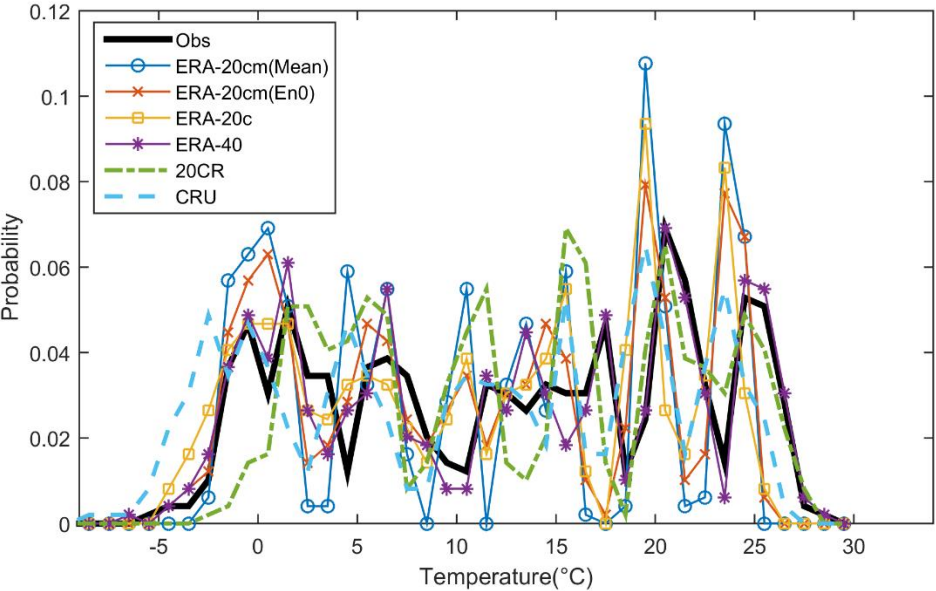
449

450 Figure 7 which illustrates the PDFs of the observed and the modelled dataset for temperature
 451 supports the skill score analysis. The performance of ERA-40 generally shows high agreements in all
 452 comparisons with the observations, but the other datasets have the seasonally biased distributions.
 453 The seasonally subdivided PDFs help to find out the difference of each dataset by comparing the
 454 peaks of them (Figure 7(b)). For the reference, the three peaks seen in spring and autumn are due to
 455 the rapid change in monthly mean temperature. For ERA-20cm mean, En0 and ERA-20c, the
 456 distributions are located in the left of the observations in the rest of the seasons except winter in
 457 Figure 7(b). Likewise, for CRUv3.23, the PDFs are located in the left side of the observation in
 458 every season (Figure 7(b)) and it causes the generally left-biased distribution in Figure 7(a). In case
 459 of 20CR, the PDF in Figure 7(a) seems to perform well except underestimation of the range of below
 460 0°C and the partial discrepancies, but the seasonal PDFs imply that this result has been refined in the
 461 process of combining seasonal discrepancies (Figure 7(b)). For instance, the second and third peaks
 462 of 20CR in spring represent the lower temperature than the real, but the PDF for winter shows the
 463 warmer temperature than the observation. This suggests that statistical usage of 20CR without
 464 considering this seasonal deviation can distort the simulation.

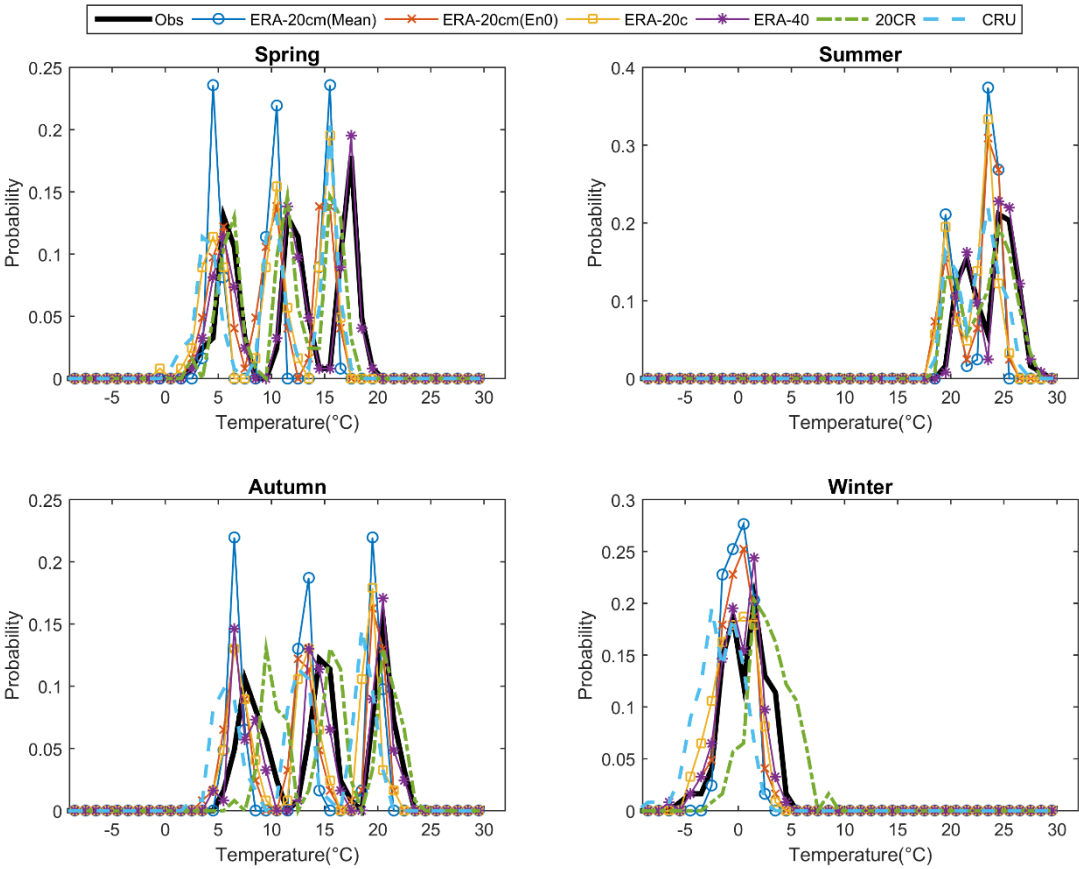
465

466 Figure 7. Probability density functions for monthly mean temperature for observation (Obs), Mean of ERA-
 467 20cm (ERA-20cm (Mean)), En0 of ERA-20cm (ERA-20cm(En0)), ERA-20c, ERA-40, 20CR, and CRUv3.23
 468 (CRU) over South Korea
 469

470 (a) PDFs for monthly mean temperature from 1961 to 2001



471
 472 (b) PDFs for seasonally subdivided monthly mean temperature from 1961 to 2001
 473



477 **Summary and Discussion**

478
479 This study evaluates the multi-decadal reanalysis datasets, ERA-20cm, ERA-20c, ERA-40 and
480 20CR, and two century-long gridded observation datasets, CRUv3.23 and GPCCv7, over South
481 Korea. The authors mainly focus on temporal and statistical applicability of monthly mean values for
482 precipitation and temperature, which are the most commonly used data in climate change study (Gao
483 et al. 2016).

484 In the temporal variability comparison for precipitation, the r values for ERA-20cm mean and En0
485 compared with the observation derived from the 13 gauged stations are closed to 0, while CRUv3.23
486 and GPCCv7 exceed 0.9 in every seasonal/annual comparison. This result reconfirms the well-
487 known feature of ERA-20cm which cannot reproduce the actual synoptic situation for precipitation
488 (Hersbach et al. 2015). On the other hand, the other reanalyses, ERA-20c, ERA-40 and 20CR, have
489 moderate to high correlations ($0.4 < r < 0.9$) and, of them, ERA-40 and 20CR have the seasonal gaps
490 comparing with the observations. This suggests that it is of importance to consider the local accuracy
491 in national-scale studies using these datasets.

492 For the trend test on precipitation, there is no significant trend except ERA-40 for summer and
493 20CR in spring and annual trends for the reference period 1961 to 2001. However, the simulation
494 from 1901 to 2010 shows the different trends depending on the dataset. CRUv3.23 and GPCCv7
495 have the identically increasing trends in summer and 12-month average simulations, whereas ERA-
496 20c shows the upward tendencies in all tests and 20CR has the decreasing trends in summer, autumn
497 and annual simulations. For ERA-20cm, the mean shows the increasing trends in spring, winter and
498 annual tests, while En0 has no significant trends. It is clear that the result of the trend analysis can
499 vary depending on the study period and regions in South Korea (Bae et al. 2008). Nevertheless, the
500 previous long term trend researches have shown that summer precipitation observed in Korea has
501 generally increased (Wang et al. 2006; Chang & Kwon 2007; Choi et al. 2009; Jung et al. 2011).

502 Chang & Kwon (2007) and Jung et al. (2011) suggested that all stations had increasing summer
503 rainfalls since 1973. Choi et al. (2009) compared the gauged rainfalls of 10 Asian countries from
504 1955 to 2007 and described the significant increasing summer rainfall in South Korea at 95%
505 confidence level. The longest trend analysis on Seoul, the capital of South Korea, also indicated a
506 significant upward trend from 1778 to 2004, although the estimate for the pre-1950 period suggested
507 no significant trend (Wang et al. 2006). Hence, the decreasing tendency of 20CR implies that despite
508 the meaningful correlation with the observation, 20CR is able to provide distorted information in the
509 long term trend analysis. In terms of the intensity of the annual trend, CRUv3.23 and GPCCv7 in the
510 test from 1901 to 2010 have the significant increasing annual slopes (mm/yr), 2.13 and 2.14. These
511 trends are different from Harris et al. (2014) which suggested 0.005 for CRU TS3.10 (CRUv3.10),
512 the earlier version of CRUv3.23, and -0.019 for GPCC version 5, the earlier version of GPCCv7, in
513 East Asia from 1901 to 2009. However, Choi et al. (2009), by evaluating the observations for the
514 1955-2007 period, showed that South Korea had a significant increasing trend (2.45) and it was
515 much higher than China (0.33) and Japan (-1.75), the other East Asia countries. This supports that the
516 slopes of CRUv3.23 and GPCCv7 have the reliability.

517 For statistical evaluation for precipitation, there are significant agreements between the monthly
518 averaged observations derived from 13 gauged stations and each dataset. The skill scores for ERA-
519 20c as well CRUv3.23 and GPCCv7, as the interpolated datasets, exceed 0.9, and the other
520 reanalyses have over 0.8 except ERA-20cm mean which has 0.66. Gao et al. (2016) concluded that
521 despite the spatial variability, all ten ensemble members of ERA-20cm for precipitation had the high
522 skill scores, over 0.8, in China. However, the two obviously different values of ERA-20cm mean and
523 En0 imply that the mean has difficulty in representing individual ensemble members. In other words,
524 an ensemble member can describe the climate change than the mean in a certain area. Nevertheless,
525 this evaluation suggests that all the reanalyses including ERA-20cm can be applied to the rainfall
526 frequency analysis as the substitution of the observation after proper bias corrections.

527 For temperature, the r values of ERA-20cm mean have moderate correlations with the observations,
528 whereas En0 performs with the low to moderate correlations. An interesting point is that the most
529 fitted dataset is ERA-40 reanalysis, not CRUv3.23 which represents the interpolated observation
530 dataset. In CRUv3.23 as well as ERA-20c and 20CR, there are the obvious gaps in the observations
531 for temperature. The earlier comparative study for temperature from 1958 to 2001 described that
532 CRUTEM2v, the earlier version of CRUv3.23, had the significantly lower temperature than ERA-40
533 in the northern hemispheres from 1958 to 1967 because of the limited availability of observations
534 (Simmons et al. 2004). However, in this study, the annual discrepancy is shown in South Korea over
535 the whole period 1961 to 2001 although it has been narrow.

536 In the temperature trend test, ERA-40 shows the identical tendencies to the observed which have
537 upward trends in spring, winter and annual simulations for the 1961-2001 period and ERA-20c,
538 20CR and CRUv3.23 also have the similarity except autumn. On the other hand, ERA-20cm mean
539 shows the significant increasing movements in spring, summer, and annual tests, whereas En0 has it
540 only in spring. Although there are trend variations according to the study period and spatial
541 distribution (Bae et al. 2008), the previous observed trends in South Korea for the late 20th century
542 suggested that the winter and annual mean temperature had the significant upward trends but the
543 summer trend was weak (Chung & Yoon 2000; Jung et al. 2002; Choi et al. 2009). Hence, it could be
544 deduced that ERA-20cm mean which shows the strong summer and weak winter trends has little
545 reliability in terms of long term trend. An interesting point is that the second trend assessment from
546 1901 to 2010 indicates the significant warming trends in all the simulations at the 0.95 confidence
547 level, although the intensity of the slopes are different depending on the dataset. This trend has been
548 shown in recent researches. Donat et al. (2016) suggested the warming trends over the world in their
549 multi data sources analysis from 1901 to 2010, and Harris et al. (2014) showed the annual warming
550 trend in East Asia, 0.11°C/decade, by using CRUv3.10 from 1901 to 2008. From this reason, the
551 increasing trends over 100yr in this paper have the reliability, although the magnitudes of them have

the uncertainty.

In the case of PDFs analysis, ERA-40 performs the best with the skill score of 0.90 and 20CR, ERA-20c and En0 as well as CRUv3.23 have the significant agreements to the observation with the values between 0.69 and 0.74. On the other hand, ERA-20cm mean has the lowest value, 0.58. This simulation indicates that these dataset have the significant reliability for the monthly frequency for temperature in Korea, but still it is challenging to apply them directly. In terms of ERA-20cm, Gao et al. (2016) showed that the skill scores of all ten ensemble members averaged over all regions in China for temperature exceed 0.9, but the skill scores for ERA-20cm mean and En0 in this study have the much lower values. This suggests that there may be a clear difference in applicability according to the region, and this gap should be explored before using the dataset in the regional scale study.

Considering the improved assimilation and ensemble technique, it is easy to hypothesise that the higher the temporal and spatial resolutions, the more accurate the reanalysis dataset should be in terms of temporal and statistical variability. However, the results in this study indicates that each dataset has its own bias and the degree of the agreement of each data can vary in space and time as shown in previous studies (Simmons et al. 2004; Bosilovich et al. 2008; Ma et al. 2009; Bao & Zhang 2013). There may be some reasons for the data uncertainty. First of all, the inhomogeneity of input data for the simulated datasets can be one of the causes (Thorne & Vose 2010; Donat et al. 2016). In other words, the further from the present, the fewer number of stations are available and it is logical to reason the increase of uncertainty for the reanalyses as well as the interpolated observation data (Ferguson & Villarini 2012; Becker et al. 2013; Zhang et al. 2013; Harris et al. 2014). It is also known that altitude gap between the modelled data and actual terrain can be one of the reasons for the significant biases in a mountainous region like South Korea (Zhao & Fu 2006; Gao et al. 2012; Gao et al. 2014a; Gao et al. 2014b). Gao et al. (2014a) showed that the biases for ERA-interim temperature data were related with the elevation difference between ERA-interim grid

577 points and gauging stations in complex terrains, but able to be reduced. Regional climate events like
578 monsoons may explain the uncertainty of the modelled data (Shah & Mishra 2014; Gao et al. 2016).
579 Shah & Mishra (2014) described that the reanalysis products like ERA-interim showed the clear bias
580 in the monsoon season precipitation and temperature over India. The resolution of gridded points
581 may also affect the uncertainty (Heikkilä et al. 2011). Heikkilä et al. (2011) compared the
582 downscaled ERA-40 with different resolutions from 30 to 10km with observations and concluded
583 that 10km resolution performed the best in complex terrains.

584 Likewise, there are numerous reasons for the uncertainty of the datasets and it is still challenging to
585 reliably reproduce climate features of South Korea by directly using a single modelled data. Hence, it
586 is necessary to evaluate the agreement between the datasets and observations and improve the quality
587 of the products in order to apply them in the regional scale analysis. Nevertheless, due to the little
588 attention on the global dataset in South Korea, this study can suggest the potentiality of the
589 reanalysis data and interpolated data as an alternative data source supplementing the lack of long-
590 term observations.

591

592

593 **Conclusions**

594

595 This study has firstly evaluated key century-long climate datasets for precipitation and temperature
596 in South Korea. From the temporal and statistical comparisons, it could be concluded that GPCCv7
597 and CRUv3.23 for precipitation and ERA-40 for temperature perform the best among the compared
598 datasets for the reference period 1961 to 2001. ERA-40, ERA-20c and 20CR for precipitation and
599 CRUv3.23, ERA-20c and 20CR for temperature have the significant agreements with the observation,
600 but they need to be improved for the application in Korea. ERA-20cm can be used for the frequency

601 analysis over South Korea on a monthly basis after bias correction, but are not suitable for the
602 temporal variability including the long-term trend. Moreover, ERA-20cm mean has difficulty in
603 representing all ten ensemble members. This paper also shows that not only reanalyses but also the
604 interpolated datasets such as CRUv3.23, which are generally accepted as the true values in the global
605 climate change study, are able to be biased depending on the region. It means that no long-term
606 dataset can be directly applied in climate impact analysis. These findings in this paper help to fill in
607 the knowledge gaps about the applicability of these datasets in South Korea, and provide a useful
608 guideline to readers from other countries on the comparative performance of the global datasets in
609 different parts of the world.

610 This study has mainly explored the monthly/seasonal/annual mean change on the basis of the
611 averaged dataset over the whole regions. This analysis is very useful for understanding the general
612 pattern of each dataset in Korea, but it does not represent the extreme climate, which is one of the
613 vital parameters in climate impact assessment. Spatial variations with the finer resolution such as
614 daily or 10km scale should be highlighted in the future study and it is essential to correct biases of
615 the model datasets. An advantage of the reanalysis data like ERA-20c and ERA-20cm by ECWMF is
616 that they supply the daily datasets with 0.125° resolution without downscaling, while the others
617 provide the coarser data. For ERA-20cm, it may be of importance to specifically assess the features
618 by all ensemble members, which has simply been explored by just both of mean and En0 in this
619 context. Hence, the bias correction for the reanalysis data with the higher spatio-temporal resolutions
620 will be explored further in the future study as well as the features of the ERA-20cm ensemble.

621

622

623 **Acknowledgements**

624

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626 (<http://apps.ecmwf.int/datasets/>). Support for the 20CR dataset was provided by the U.S. Department
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629 supplied from their websites, <https://crudata.uea.ac.uk/cru/data/hrg/> and <http://gpcc.dwd.de>,
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